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Tracking and Predicting Fine Scale Sea Ice Motion by Constructing Super-Resolution Images and Fusing Multiple Satellite Sensors

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LONG-TERM GOALS

Tracking and predicting the fine scale sea ice motion will be particularly critical to safe Navy operations in the Arctic Ocean. It is also very important to monitor and track the size, shape, and location of sea ice in near real-time (within several hours of data acquisition), and predict the motion of sea ice for ice hazard forecasts in a finer scale than is currently possible. The log-term goal of this project is to explore new algorithms for the purpose of constructing and analyzing super-resolution images from multiple satellite sensors for automatic tracking and prediction of fine scale sea ice motion in Arctic Ocean.

OBJECTIVES

The objective of our proposal is to: 1) construct super-resolution images from satellite sensors which will significantly improve the tracking of sea ice motion from a coarse scale to a finer scale; and 2) implement data fusion methods to combine data from passive microwave and other satellite sensors to produce more accurate tracking and prediction of sea ice motion.

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APPROACH

We propose to explore new algorithms to construct and analyze **super-resolution** images from multiple satellite sensors for automatic tracking and predicting **fine scale** motion of Arctic sea ice. Our research efforts will focus on the following main tasks:

a) ***Constructing super-resolution images from multiple satellite sensors (Dr. Yingli Tian and students):*** There are many methods for constructing super-resolution images for video surveillance and image retrieval. We will extrapolate and adapt selected techniques to construct super-resolution images from satellite imagery that has a resolution at least 5 times higher than that of the original satellite imagery.
b) ***Tracking sea ice motion from multiple satellite sensors and passive microwave sensors (Drs. Tian, Meier, and students):*** We will develop robust methods to automatically track sea ice motion from passive microwave sensors and multiple satellite sensors respectively.
c) ***Fusion of passive microwave sensors and multiple satellite sensors to track fine scale sea ice motion (Drs. Tian, Meier, and students):*** We will develop new fusion algorithms to effectively integrate data from multiple sensors for sea ice motion monitoring.
d) ***Predicting the fine scale sea ice motions (Drs. Tian, Weiss, and students):*** We will develop prediction models to represent the motion and changes of ice parcels by using motion history obtained from the sea ice tracking.

WORK PROGRESS

The project started from March 2013. Currently, we are focusing on the task of "***Constructing super-resolution images from multiple satellite sensors".*** The progresses we have accomplished are described as following:

1. Developing New Super Resolution Algorithms: Image super-resolution is to restore a high resolution image from one or multiple low resolution images which is an essential operation in many applications. It is a challenging task to restore sharp edges while still maintains rich and natural texture. We are developing a novel gradient-based single image super-resolution method which takes benefit from internal across-scale similarity as well as external gradient statistics to fully recover realistic texture information. The proposed algorithm is able to create clean edge with minimal visual artifacts while constructing fine detailed texture information which respects the input image. Our preliminary experiment results demonstrate that the proposed method achieves the state-of-art results. Moreover, our proposed algorithm is easily scalable to include multiple input images.

2. Investigating the satellite data for our research: Initial efforts have focused on finding useful regions to collect satellite data. Passive microwave data is available in all sea ice conditions and provides complete daily coverage. However, spatial resolution is coarse and smaller-scale motions cannot be determined from passive microwave data. Other sensors are more limited, but potentially provide more detailed data. Initial assessments have been made on MODIS data in terms of its suitability. While clouds obscure substantial regions of the Arctic at any given time, we have found that enough clear sky exists to obtain incomplete but reasonable fields of motion estimates.

Data from Aqua, Terra, and Suomi NPP satellites were investigated. Aqua and Terra are older satellites that fly the MODIS instrument. Suomi is a newer satellite which flies the VIIRS instrument. MODIS and VIIRS are scanning radiometers. All three satellites orbit the earth in 98 degree retrograde sun synchronous orbits, which provide them with views of the Arctic Ocean on every orbit. Between the three satellites, every point on the Arctic Ocean is viewed at least three times each day. The swaths that MODIS and VIIRS view are very wide (2330 km for MODIS and 3040 km for VIIRS). The near polar orbits of the satellites cause the swaths of each satellite to converge and greatly overlap at the poles on multiple orbits. Therefore, on any one day many points on the Arctic Ocean will be viewed more than three times. For any particular point, some views will be near nadir and many of the views will have significant slant angles. With a 98 degree inclination, nadir during the most northern reach of each orbit will be at 82 degrees north. As an example, 82 degrees north is less than 1000 km from the North Pole. Therefore, every orbit of all three satellites views the North Pole, even though it is always far from nadir.

MODIS detects light in wavelengths from 405 nm to 14.385 um. The light detectors are divided into 36 different spectral bands. The resolution of the detectors range from pixels that are 250 meters square to pixels that are 1000 meters square. In comparison, VIIRS has 22 spectral bands with wavelengths from 402 nm to 12.48 um. Pixel sizes range from 371 meters by 387 meters to 742 meters by 776 meters. MODIS and VIIRS imagery data are both available online. Data is divided into segments of orbits. Each segment is referred to as a granule. Each granule represents 5 minutes of flight time. Therefore, a MODIS granule is approximately 2030 km long and 2330 km wide, and a VIIRS granule is approximately 2030 km long and 3040 km wide.

3. Locating the geographic locations for our research: In addition to general issues of coverage, higher spatial resolution imagery is more unwieldy to use for large file sizes and thus it makes sense to at least initially focus on one or two key regions. We have chosen to first look in the Beaufort and Chukchi sea region for several reasons. First, because it encompasses U.S. territorial waters, it is of key interest to the Navy. Second, it is a region of increasing economic interest due to the potential for extraction of natural resources. Third, it is a region where changes in the sea ice are dramatic. Recent summers have seen extremely low ice, with the edge receding several hundred kilometers from the coast. However, this summer provided an interesting contrast, with late melt onset and the edge staying much nearer to the coast. This was despite the fact that the preceding winter saw substantial sea ice dynamics, with many large leads forming during February and March (http://earthobservatory.nasa.gov/IOTD/view.php?id=80752). Such variability has important ramifications for forecasting and operational activities in the region.

Working plan for Oct. 2013 -- Sept. 2014:

1. We will continue to improve and refine the image super-resolution algorithm and apply it to satellite data.

2. We will develop object tracking method to track multiple objects in crowded environments. The algorithm will be applied to ice fragment tracking.

3. We will acquire satellite data at specific geo-locations and time. The data should be annotated to track specific ice fragments and analyzed for predicting ice moving model. The super-resolution algorithms will be applied to generate images with finer resolution than the original MODIS and VIIRS imagery. The motion of the ice fragments will be tracked on the finer resolution images. The ice fragments will be first manually initialized on the first image frame while our research focusing on tracking method.

RESULTS

1. Preliminary results of super resolution algorithm: The listed experimental results below demonstrate the feasibility of our proposed super-resolution algorithm in large upscaling factors. Sample image used in Figure 3 is very challenging due to the extreme richness and complexity of MODIS sea ice data. However, our proposed method reconstructs clean edges of the ice fragments for further tracking purpose.

Figure 1: Super-resolution result on ‘kid’ (4 ×). Left is the input image; right is the result after the proposed algorithm. Results are better viewed in the zoom-in boxes.

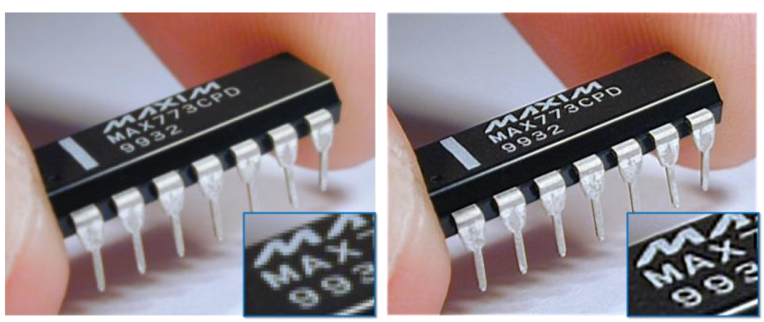

Figure 2: Super-resolution result on ‘chip’ (8 ×). Left is the input image; right is the result after the proposed algorithm. Results are better viewed in the zoom-in boxes.

2. The passive microwave sea ice product distributed by NSIDC has been updated through 2012 and will soon be made public (pers. communication, Donna Scott, NSIDC). This is the first update since 2006 and will provide an updated product to work with. The ice motion software has also been obtained, so that our investigating team can potentially run motions directly. We have also determined useful locations and time periods to acquire imagery and sample images have been collected.

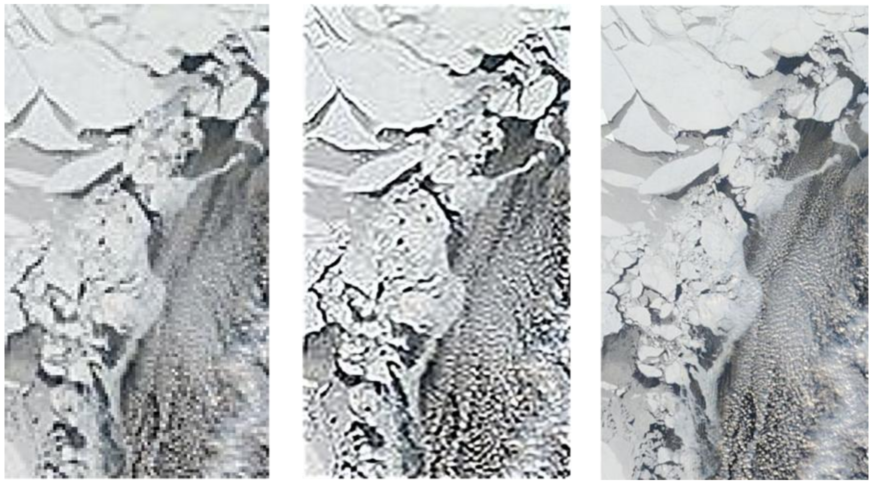

Figure 3: Super-resolution result on sample MODIS image (4 ×). Left is the input image; middle is our reconstructed result; right is the ground truth (GT) image. Both input image and the GT image are captured from http://rapidfire.sci.gsfc.nasa.gov/imagery/subsets/?subset=Arctic_r02c04.2013070.terra with resolutions of 1km and 250m respectively.

3. Locating the geographic locations: Discussions with Navy Task Force Climate Change have indicated that the Beaufort Sea would be an appropriate initial area of interest from a Navy perspective. The Beaufort Sea is also of great interest from a purely scientific perspective. In early 2013, storms in the Beaufort Sea resulted in large areas of open ocean. The area 125 W long to 135 W long and 70 N lat to 75 N lat in the time period January 2013 through March 2013 will be used as the initial Arctic Ocean area on which this project will focus.

In October 2011 a NASA IceBridge flight spotted a large crack in the Pine Island Glacier in West Antarctica. Even though the glacier is not sea ice and it is not in the Arctic, a great deal is now known about the dimensions of the crack as it expanded over time and eventually caved a large iceberg on 8 July 2013. MODIS imagery is available for this time period and has been obtained. There are also finer resolution images of the crack. These will be used for ground truth experiments to test and calibrate the super-resolution algorithms.

IMPACT/APPLICATIONS

In addition to ice tracking, the proposed super resolution methods can be used for many other applications. The strong collaboration among the three PIs (Dr. Tian from CCNY, Dr. Meier from NASA, and Dr. Weiss from NUWC enhance the long-term collaboration among these organizations and will bring research opportunities for the students at CCNY to solve problems in real applications.

RELATED PROJECTS

W. Meier: A Lagrangian to emerging dynamics in the marginal ice zone, ONR, Award Number N000141110977, B. Tremblay, PI – this project uses the passive microwave derived sea ice motions to track parcels of ice to investigate changes in the source and sink regions of Arctic sea ice and to compare with CMIP5 model estimates.